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Is the Sky the Limit? An Analysis of High-Rise Office Buildings

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Abstract
Modern central business districts are characterised by high-rise office buildings. Helsley and Strange (2008) argue that skyscrapers are caused by agglomeration economies and a prize for being the tallest, so a reputation effect. We aim to test the relevance of this model by investigating the impact of building height on commercial office rents. The results show that firms are willing to pay about 4 percent more for a building that is 10 meters taller, which we interpret as the sum of a within-building agglomeration effect and a reputation effect. Using semiparametric techniques, we disentangle reputation effects from agglomeration effects and demonstrate that the reputation effect is substantial for tall buildings. For example, it is at least 17.5 percent of the rent for a building that is 6 times the average height.

Keywords: commercial buildings, building height, landmarks, reputation effect, semiparametric regression, agglomeration effect
JEL Classifications: R30, R33

I. Introduction

In contemporary cities, skyscrapers are an increasingly common sight in areas where rents are high. Urban economists usually assume that high density buildings are merely the result of a high price for land, which provides an incentive to economise on land and to increase expenditure on building capital (Mills, 1967; Lucas and Rossi-Hansberg, 2002). However, it is argued that the presence of very tall buildings cannot be fully explained by standard urban economic models (Helsley and Strange, 2008; hereafter HS). HS indicate that skyscrapers arise from two additional basic forces. First, workers may be more productive in skyscrapers, which we label as *within-building agglomeration economies*. Tall buildings imply an extreme density of workers, allowing for internal returns to scale (Gold, 1981). As almost all tall buildings are offices that host many tenants, within-building external returns to scale may also play a role. An important source of external returns encompasses face-to-face contacts, leading to knowledge spillovers between workers (Marshall, 1890; Storper and Venables, 2004; Combes et al., 2008).[1] Moreover, Jacobs (1969) argues that a diverse portfolio of firms may lead to product innovations and new combinations. Arzaghi and Henderson (2010) show that most of these externalities take place within a very close distance from the firm location, especially for high-end business services. Within-building interactions are more likely than between-building interactions because restaurants, gym facilities, etc. are shared among workers of the same building. Moreover, the low time cost of vertical (within-building) transportation using elevators (compared to horizontal transportation) stimulates interactions and leads to the construction of tall buildings, even on cheap land (Sullivan, 1991).

Second, HS point out that there is an inherent value placed on being the tallest, *a reputation effect*. A developer may receive a prize (social status, reputation etc.) when it constructs tall buildings.[2] This may lead to overbuilding, as a builder has an incentive to construct a building that is taller than the welfare-maximising one. Given a competitive building industry, this reputation effect must capitalise in office rents, i.e. firms have a preference to locate in tall buildings that are landmarks, as a favourable reputation allows firms to set higher prices, attract investors and attract a talented workforce (Klein and Leffler, 1981; Milgrom and Roberts, 1986; Eichholtz et al., 2010).[3]

Although the construction of tall buildings requires enormous investments and receives much attention in the media, the economics of building height are underexposed. The literature heavily

[1] Another source is dense input-output linkages between buyers and suppliers. However, such linkages likely account for only a small part of clustering of firms (Storper and Venables, 2004).
[2] In their theoretical model, HS assume that only the tallest building gains additional value. In reality, one may expect that, for example, the ten tallest buildings in a certain area generate an additional mark-up.
[3] We ignore here the effect on workers. Workers may prefer to work in tall buildings because of better views as well as reputation. Note that these are non-taxed consumption goods, whereas wages are taxed as income. In addition, reputation is a good with positional externalities. From a welfare perspective, it is then plausible that firms oversupply building height and undersupply wages (Katz and Mankiw, 1985; Gutiérrez-i-Puigarnau and Van Ommeren, 2011).

relies on studies that theoretically investigate the development of skyscrapers and high-rise buildings (Arnott and McKinnon, 1977; Grimaud, 1991; Sullivan, 1991; Bertaud and Brueckner, 2005; HS). Empirical evidence is limited to studies which confirm that height competition is a determinant of building height, although this only holds for a small portion of the building stock (Barr 2010a; 2010b). To what extent taller buildings receive rent premiums, and more specifically, whether there is a reputation premium, is unknown.

In this paper, we will estimate the willingness to pay (WTP) for tall buildings in the commercial real estate market using an extensive dataset on office transaction prices. Using a hedonic price framework, we aim to distinguish between the price effect due to within-building agglomeration effects and due to reputation, while controlling for other building and location characteristics. We take into account the role of unobserved characteristics by including area fixed effects at a very low level of aggregation and employing an instrumental variables approach, where the presence and height of nearby buildings that are constructed before World War II are used as instruments for building height.[4] In this way, we also control for spatial variation in prices that is due to variation in the demand for land as indicated by standard urban economic theory (Fujita, 1989). In addition to standard hedonic price estimation approaches, we also investigate whether building height is nonlinearly related to rents employing a semiparametric control function approach. The latter approach enables us to identify the (minimum) reputation effect. This effect can be disentangled from within-building agglomeration effects by assuming that the marginal agglomeration effect is diminishing in height, which is in line with HS. It is important to note that, although in the Netherlands, maximum building height restrictions are common, hedonic price analyses are still applicable.

The results show that firms are willing to pay about 4 percent more to locate in a building that is 10 meters taller. It appears that the willingness to pay for building height is highly nonlinearly related to rents, and the marginal effect is non-monotonic. We then demonstrate that the reputation effect is at least 17.5 percent of the additional rent for a building that is 6 times the

[4] If locations are attractive for firms for unobserved reasons, one expects that buildings are higher and rents are higher, causing a spurious positive correlation between rents and building height (Bayer and Timmins, 2007; Combes et al., 2008). However, zoning plans may force firms to cluster at, ceteris paribus, unattractive locations (as attractive locations are reserved for residential land use), which causes a spurious negative correlation.

average height. We only find evidence of *within*-building agglomeration benefits, and not of *between*-building agglomeration effects, suggesting that interactions between workers are an extremely local phenomenon (see Arzaghi and Henderson, 2008). We also derive the welfare costs of height restrictions that are shown to be higher than when a constant rent over building height is assumed (which is the standard assumption in the literature on regulatory constraints, see Glaeser et al., 2005; Cheshire and Hilber, 2008).

This paper continues as follows. In Section II, we briefly discuss a sequential model of skyscraper development, proposed by HS, and considers the estimation procedure. In Section III, we elaborate on the regional context, data and identification strategy. In Section IV we present and discuss the results, including a robustness analysis. Section V concludes and derives some policy implications.

II. Model and methodology

A. The Helsley and Strange Model

Let's assume a city with many locations, wherein tenants occupy one unit of floor space. The profit function of a tenant located in building i is then given by $\pi_i = pq(h_i) + \nu - r_i$, where p denotes the price of output q, h_i is the height of building i (in terms of floors), r_i represents the rent for floor space and ν is a premium for locating in the tallest building, $\nu > 0$ if $h_i > \max(h_{-i})$, and equals zero otherwise, where $-i$ denotes other buildings in the city.[5] A tenant's output is a concave function of building height in which the tenant resides, as taller buildings offer more opportunities for agglomeration economies. Given a perfect competitive market (so $\pi = 0$), the bid rent r_i is equal to $pq(h_i) + \nu$.

Let's also assume identical profit-maximising developers that construct office buildings. The profit of builder at location i is $\kappa_i = r_i h_i - c(h_i)$, where $c(\cdot)$ is an increasing and convex cost function.[6] The profit-maximising building height for location i then satisfies the following first-

[5] Our model slightly deviates from HS. We allow the building production function to be a function of its own building height (to allow for increasing returns to scale with respect to building height) and include the reputation effect ν directly into the rent function. These differences are not essential and do not change the main message of the model.
[6] Building height is a better proxy to capture agglomeration economies than building volume for two reasons. First, creating low but larger buildings does likely not lead to higher marginal construction costs, so conditional on building height, firms can choose building size at no additional costs and hence, there is

order condition: $ph_i(\partial q(\cdot)/\partial h_i) + pq(\cdot) + \nu - \partial c(\cdot)/\partial h_i = 0$. Similar to HS we may write the payoff of a construction firm with respect to h_i as $\kappa_i(h_i) + \nu h_i$, where $\kappa_i(\cdot)$ is an increasing and concave function. Let h_i^* denote the profit-maximising building height in absence of a premium for being the tallest $(\nu = 0)$ and h_i^w denote the pre-emptive building height. HS prove that if builders choose sequentially with builder i choosing first, builder i will choose $h_i = h_{-i}^w$. With identical builders $\kappa_i(h_{-i}^w) + \nu h_{-i}^w = \kappa_i(h_i^*)$. In order to win the contest, builder i overbuilds relative to the profit maximising building height and the other developers will concede and choose $h_{-i} = h_{-i}^*$. In the current set-up, the prize completely dissipates.[7] We emphasise that the current model assumes that the prize only applies to the tallest building, while it is plausible that the prize applies to more than one building, also because a building may be the tallest building in a specific city or neighbourhood.

Two implications for our empirical work can be derived. First, commercial rents are expected to be positively related to building height because of within-building agglomeration economies. Second, given a concave function of these agglomeration economies, building height must have a concave effect up to a certain height. After that concavity is expected to be weakened due to reputation effects. Given a strong reputation effect, the effect of building height may become convex for very tall buildings.

B. *A hedonic framework*

The standard procedure to investigate the impact of property and neighbourhood attributes on commercial property values is to assume a specific functional form and then regress the price of floor space on the variables of interest and a wide range of control variables. Let p_i denote the price per square meter of a rental property i and h_i the height of its building. We furthermore include control variables x_i, including the log of size of the rental property, and location dummies d_i to control for unobserved heterogeneity. We start assuming a standard loglinear functional form:

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no premium for large buildings. Second, tall, rather than large, buildings imply an extreme density of workers (e.g. industrial buildings usually have a large surface area, but do not host many workers). We come to this issue in more detail in the sensitivity analysis (section 4C).

[7] HS extend this analysis by considering a simultaneous game with a mixed strategy equilibrium and show that this leads to overbuilding for all developers, but the amount of overbuilding decreases when lots are more similar and the number of developers rises.

$$\log p_i = \alpha h_i + x_i'\beta + d_i'\gamma + \xi_i, \tag{1}$$

where α, β and γ are parameters to be estimated and ξ_i denotes the property's attributes that are not observed by the econometrician. We assume that ξ_i enters as an additive term. Equation (1) may be estimated using ordinary least squares (OLS) or instrumental variables (IV), when h_i is correlated with ξ_i.

It is often argued that the nature of the relationship between the price and the attributes is complex and highly nonlinear (Ekeland et al., 2004; Bajari and Benkard, 2005, McMillen, 2010). So, it is preferred to use a nonparametric model rather than (1). Because the price of the rental property is a function of numerous attributes, including many area fixed effects, it would be infeasible to estimate a fully nonparametric hedonic price function. We therefore choose a partially linear specification in which only h_i is nonparametrically related to the rental price:

$$\log p_i = \Omega(h_i) + x_i'\beta + d_i'\gamma + \xi_i, \tag{2}$$

where $\Omega(\cdot)$ is some function of building height. As equation (2) is partially linear, we employ the Robinson procedure. First, we regress $\log p_i$, x_i and d_i on h_i nonparametrically. Then, we regress the residuals of $\log p_i$ on the residuals of x_i and d_i. This leads to $\sqrt{N}$-consistent estimates for β and γ. Robinson (1988) showed that the coefficients are estimated at parametric rates of convergence, despite the presence of a nonparametric part. The last step is to regress $\log p_x - x_i'\hat{\beta} - d_i'\hat{\gamma}$ nonparametrically on h_i.

We estimate $\Omega(\cdot)$ by local linear regression techniques.[8] Locally weighted regression is the most common nonparametric approach to analyse spatial data (McMillen and Redfearn, 2010). So, one estimates for each observation a weighted regression based on a kernel. We employ a Gaussian kernel where the weight variable is defined as the difference between building height of two observations i and $\tilde{\imath}$:

$$k_{\tilde{\imath}i} = \frac{1}{\rho\sigma_h\sqrt{2\pi}} \mathrm{e}^{-1/2((h_i - h_{\tilde{\imath}})/\rho\sigma_h)^2}, \tag{3}$$

where $k_{\tilde{\imath}i}$ is the kernel weight of $\tilde{\imath}$ in the local regression of i and ρ is the bandwidth. A lower bandwidth leads to a lower mean-squared error, but to a higher variance of the estimator. A

[8] We prefer estimating $\Omega(\cdot)$ by local methods, opposed to the use of a polynomial approach, cubic smoothing splines or Fourier analysis, as the interpretation of the *local* coefficients is easier and comparable to the *global* coefficient of building height of equation (1) (see McMillen, 2010, for details). Locally weighted regression methods also have a lower asymptotic bias than the Nadaraya-Watson estimator and a lower asymptotic variance than the Gasser-Müller estimator (Bajari and Kahn, 2005).

larger bandwidth may create a larger bias when the underlying function is nonlinear (Fan and Gijbels, 1996).[9] The estimation procedure is not standard because building height may be endogenous. To account for endogeneity, we employ a control function approach (CFA) (see Holly and Sargan, 1982; Yatchew, 2003). So, we assume that there are instruments z_i that are uncorrelated with ξ_i but correlated with h_i. In the first stage, we regress building height on z_i, x_i and d_i semiparametrically:

$$h_i = \Phi(z_i) + x_i'\delta + d_i'\zeta + \eta_i, \tag{4}$$

where $\Phi(\cdot)$ is some function of the instruments and δ and ζ are coefficients to be estimated, using the Robinson procedure. We then insert the residuals η_i as a control function into (2) (see Blundel and Powell, 2003).[10]

III. Regional context, data and instruments

A. Regional context

Our analysis is based on information for three major Dutch cities Amsterdam (the capital), Rotterdam (a major port city) and Utrecht, which are respectively the largest, the second and fourth largest city in the Netherlands. These three cities combined have 1.7 million inhabitants, about 10 percent of the Dutch population, but their combined share in the office market is about 25 percent (Bak, 2009). All cities are part of the Randstad (see Figure 1).

Both Amsterdam and Utrecht have protected historic city centres, which puts strong restrictions on the construction of new (tall) buildings. The city centre of Rotterdam was bombed in World War II leading to a complete redevelopment of this area. Nowadays it is the only Dutch city with an American-style central business district with high-rise commercial (and residential) buildings. Figures 2-4 illustrate the spatial structure of the selected cities. In Rotterdam and Utrecht, building height is generally decreasing in distance to the city centre,

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[9] Our bandwidth is based on the Silverman's rule of thumb, which is given by $1.06\sigma_h(n^{-1/5})$, where n is the number of observations. Because Silverman's rule tends to undersmooth the hedonic price function, we multiply the bandwidth with two, which is a moderate number. For example, Bishop and Timmins (2008) multiply their 'optimal' bandwidth with five and interpret that as the best bandwidth.

[10] The control function is estimated using a fifth-order polynomial. The main advantage of using a series estimator is that we can employ the semi-parametric estimation procedure of Robinson (1988) to estimate $\log p_i = \Omega(h_i) + x_i\beta + d_i\gamma + \Xi(\eta_i) + \xi_i$, where $\Xi(\cdot)$ demotes the control function. Otherwise, very computational intensive procedures such as backfitting have to be employed (Yatchew, 2003).

whereas in Amsterdam it is first increasing and then decreasing in distance to the city centre (see Figure A1 in Appendix A).[11]

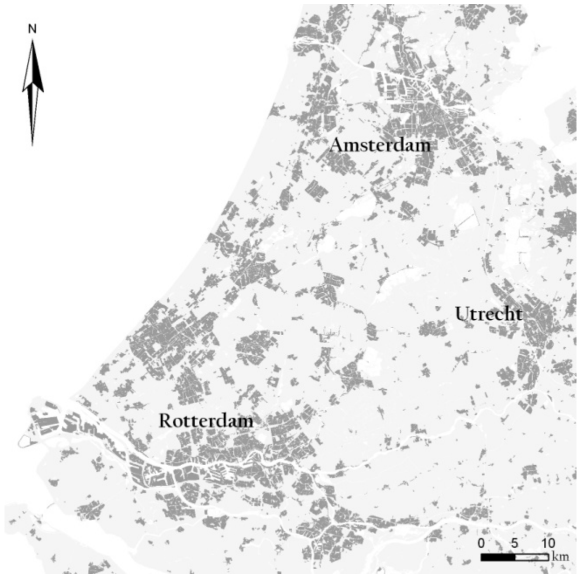

FIGURE 1 — OVERVIEW MAP OF THE RANDSTAD

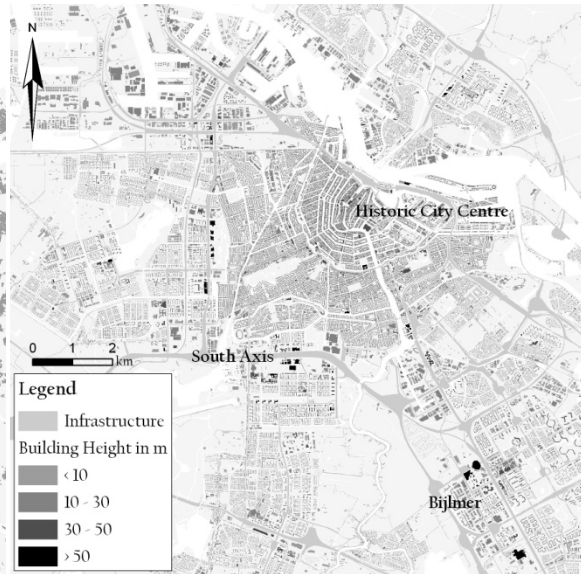

FIGURE 2 — MAP OF AMSTERDAM

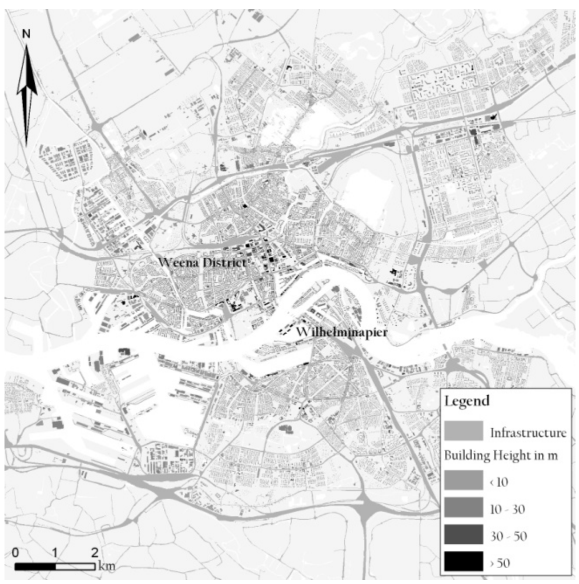

FIGURE 3 — MAP OF ROTTERDAM

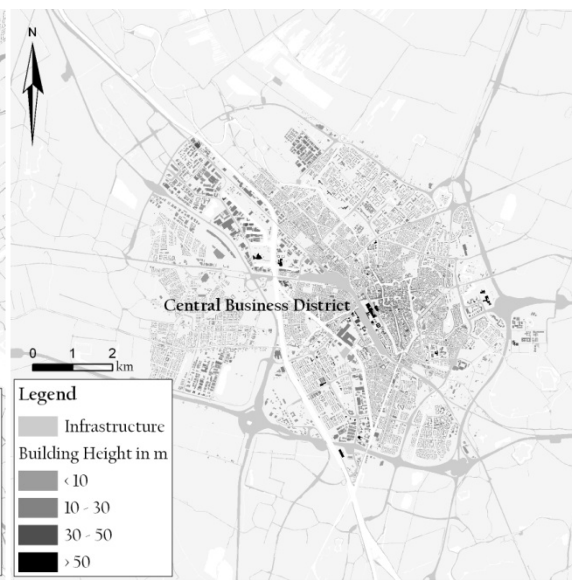

FIGURE 4 — MAP OF UTRECHT

[11] Amsterdam has a somewhat dispersed urban structure: businesses are concentrated in the city centre, but also at the South Axis and in the Bijlmer area. In Rotterdam most businesses are concentrated in the city centre, along the axis Weena-Wilhelminapier, although there are secondary subcentres (such as Alexander). Utrecht has only one substantial business centre with some high-rise buildings near the central railway station.

'Skyscrapers' only recently became a feature of European cities. In the Netherlands, there are 20 commercial office buildings taller than 100 meter (see Table 1), of which 18 are constructed after 1990, so the construction of skyscrapers is booming, as suggested by Helsley and Strange (2007). 7 of the 20 tall buildings are located in Rotterdam, 6 in Amsterdam and only one in Utrecht. The tallest building in the Netherlands is only recently constructed and is 165 meters tall.

TABLE 1 — 10 TALLEST OFFICE BUILDINGS IN THE NETHERLANDS

	Name	Height in m	Const. Year	Floors	City
1	Maastoren	164.75	2009	44	Rotterdam
2	Delftse Poort	151.35	1991	41	Rotterdam
3	Hoftoren	141.86	2003	29	The Hague
4	Rembrandttoren	135.00	1995	35	Amsterdam
5	Millenniumtoren	131.00	2000	34	Rotterdam
6	World Port Center	123.00	2001	32	Rotterdam
7	Mondriaantoren	123.00	2002	32	Amsterdam
8	Carlton	120.00	2009	31	Almere
9	Achmeatoren	115.00	2002	24	Leeuwarden
10	Erasmus MC	114.27	1969	27	Rotterdam

B. Data

We make use of three datasets. The first dataset is gathered by Strabo and NVM and consists of transactions of commercial office properties, provided by real estate agents between 1990 and 2010. The property dataset contains information on the transacted rent, rental property attributes, such as address, size (gross floor area in square meters), and whether the building is newly constructed or renovated.[12] The data also provides information on the particular real estate agent that is involved in the transaction. The second dataset provides information on the exact location, construction year and building height (obtained from the Department of Infrastructure and Environment) for *all* buildings in Amsterdam, Rotterdam and Utrecht (see Koomen et al.,

[12] We have also information on sales prices. The main reason that we do not use this information here is the limited number of observations (only 436), less than 10 percent of the number of rent transactions. The low percentage of owned properties is due to two reasons. First, in the office market it is uncommon that users own properties. Second, renting firms are generally more mobile leading to more transactions. We also note that office buildings that are rented are more often occupied by many firms compared to buildings that are sold. In the rental property market, we may therefore expect that external within-building agglomeration effects are more relevant.

2008 for more details). The third dataset, the *Rijksmonumentenregister* (Listed Building Register) provides information whether buildings are listed.

Our analysis is based on 4,792 transactions, about a half for Amsterdam and 25 percent for both Rotterdam and Utrecht. [13] In the analysis, we control for a range of locational attributes.[14] First, we add 145 postcode fixed effects, so we have on average 33 observations per postcode.[15] The average distance of a building to all other firms within the same postcode area is only 474 meters. Besides these fixed effects, we include dummy indicators whether a property is within 150 meters of a highway, rail line, park or water and within 250 meters of the nearest railway station. We also control for the number of listed structures within 150 meters of the rental property. Furthermore, we account for the average construction year of nearby buildings, as well as nearby building volume (the height of buildings multiplied by their surface area), both measured within 250 meters.[16] To include the latter is potentially important, as a tall building may be a proxy for a dense urban district where agglomeration economies are expected to be high. In our analysis we will include dummies for the 10 largest real estate agents to control for differences in service levels and specialisation of real estate agents in specific types of offices.

Descriptive statistics are presented in Table A1 of Appendix A. The yearly rent per square meter is on average € 143. The average building height is 29 meters. However, this measure is somewhat misleading, as taller buildings also host more rental properties. The building-weighted average height of buildings in our sample is indeed lower and equal to 21 meters (where the weights are inversely proportional to the number of observations per building). About 40 percent of rental properties are in buildings lower than 20 meters, but most, 43 percent, are in buildings between 20 and 40 meters. About 4 percent of the observations are in buildings taller than 80 meters and 1 percent are in buildings taller than 100 meters.

[13] We exclude transactions with missing height data, yearly rents per square meter lower than € 50 or higher than € 500 and rental properties that are less than 50 or more than 25,000 square meters.
[14] Eichholtz et al. (2010) argue that there are three approaches to correct for spatial variation in prices. First, by including dummies for each submarket. Second, by focusing on a specific city or metropolitan area and third, by including locational variables such as distance to railway stations etc. We combine those approaches: we focus on three Dutch cities, include location dummies *and* control for a wide range of locational attributes.
[15] Postcode areas are comparable to census tracts in the US.
[16] We do not have information on whether nearby buildings are residential, commercial or mixed.

The average floor size of rental properties is 1,130 square meters (about ten times the average size of residential properties). The correlation between rental size and building height is 0.11, so rather low. So, it is unlikely that especially larger firms (in terms of rental size) occupy tall buildings, because these buildings offer space for possible future expansion. The *average* construction year is 1933, so, on average, buildings are quite old in these three cities. This is due to many historic buildings in city centres of Amsterdam and Utrecht (but not in Rotterdam). However, at the same time, about 43 percent of the rental properties are rather new and in buildings that are constructed after 1980.

C. Instruments

A positive effect of building height on rents is non-causal when unobserved location and building characteristics are correlated with building height. Given that we include area fixed effects, unobserved characteristics must be very local and may include trendy restaurants or cafés which are popular socialising spots, but also characteristics related to the quality of the building (see Arzaghi and Henderson, 2008).[17] We therefore need instruments that are correlated with building height but uncorrelated with these unobserved factors.

We start with an analysis using two instruments. The first is a dummy variable indicating whether there are pre-war buildings (within 250 meters of the rental property).[18] As in other European countries, conservation regulations are very tight, especially in historic city centres (see Cheshire and Hilber, 2007). When there are pre-war buildings in vicinity, the height of new buildings is lower, because new construction is not allowed to damage the pleasing character of the neighbourhood (Bertaud and Brueckner, 2005). This holds for the historic city centres of Amsterdam and Utrecht, but also for a large number of neighbourhoods in Rotterdam that are near the city centre but were not bombed during World War II.[19] The instrument's validity rests

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[17] For example, we do not control for vacancy rates of office buildings. This may be a problem when building height and vacancy rates are highly correlated and the vacancy level affect prices. Our IV approach addresses this issue.

[18] We have chosen 1940, as buildings constructed before the war are frequently aesthetically pleasing and tend to receive a premium in the residential housing market.

[19] This does not mean that in other neighbourhoods height constraints do not apply. For example, in Utrecht developers are not allowed to construct buildings that are taller than twice the height of buildings in the neighbourhood (Municipality Utrecht, 2005). In general, however, constraints in new

on the assumption that the presence of pre-war buildings is unrelated to current demand for location and building endowments (see, similarly, Ciccone and Hall, 1996; Arzaghi and Henderson, 2008). We believe this is a plausible assumption, as offices are mainly used by business services. The main input of business services is labour and not natural resources or capital, so it is likely that endowments that were important at least 50 years ago are totally different from the current unobserved endowments.[20] This is especially reasonable because we condition on building volume in the neighbourhood, the number of listed structures in vicinity, the average building construction year in the neighbourhood and because we include area fixed effects.

We also include an instrument indicating the average building height of pre-war buildings in vicinity. Conditional on the presence of pre-war buildings, the height of these buildings is positively correlated with current height. In a sensitivity analysis, we will use other instruments (population density in 1830 and distance to station in 1870), to demonstrate that our results are robust to the choice of instruments.

IV. Results

A. Main results

The results for four specifications are presented in Table 2. In Specification (1), we use ordinary least squares regression techniques. We observe that building height is positively related to commercial office rents, as expected: we find that a 10 meters increase in building height leads to a 3 percent increase in rent per square meter.[21] In Specification (2), we categorise building height into four dummy variables. Now, we find that buildings taller than 100 meters are 40 percent more expensive than buildings lower than 20 meters (price per square meter). The building height effect is nonlinear, as the effect is about the same for buildings between 40-60 and 60-80 meters, while it increases afterwards.

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neighbourhoods are less binding and it is possible to obtain permits to construct tall buildings under certain circumstances.

[20] For example, in Europe, cars only became a familiar mode of transport after World War II. Pre-war locational policies regarding the construction of offices were therefore substantially different from contemporary zoning plans, as commuting costs (per unit of time travelled) were much higher.

[21] We investigate whether there is a positive correlation between building height and the area fixed effects, as we may expect that buildings are taller on locations that have rents that are higher for unobserved reasons. However, it is observed that there is a very weak *negative* correlation (-0.04).

TABLE 2 — HEDONIC ANALYSIS OF OFFICE RENTS
(dependent variable: logarithm of rent per square meter)

	(1) – OLS	(2) – OLS	(3) – IV	(4) – CFA
Building Height *(in 10m)*	0.030 (0.002) **		0.042 (0.014) **	0.048 (0.010) **
Building Height 20-40m		0.052 (0.008) **		
Building Height 40-60m		0.111 (0.014) **		
Building Height 60-80m		0.126 (0.016) **		
Building Height 80-100m		0.161 (0.022) **		
Building Height >100m		0.407 (0.031) **		
Floor space *(log)*	-0.001 (0.003)	-0.001 (0.003)	-0.001 (0.003)	-0.001 (0.003)
New Building	0.051 (0.010) **	0.050 (0.010) **	0.047 (0.011) **	0.051 (0.011) **
Renovated Building	0.021 (0.012)	0.017 (0.012)	0.020 (0.012)	0.019 (0.013)
Listed Building	0.019 (0.014)	0.017 (0.014)	0.018 (0.014)	0.018 (0.013)
Construction Year 1951-1960	-0.015 (0.019)	-0.022 (0.019)	-0.013 (0.018)	-0.019 (0.019)
Construction Year 1961-1970	-0.102 (0.016) **	-0.107 (0.016) **	-0.108 (0.017) **	-0.100 (0.016) **
Construction Year 1971-1980	-0.026 (0.013) *	-0.033 (0.013) *	-0.031 (0.013) *	-0.033 (0.014) *
Construction Year 1981-1990	0.071 (0.012) **	0.062 (0.012) **	0.066 (0.013) **	0.066 (0.012) **
Construction Year 1991-2000	0.118 (0.014) **	0.115 (0.015) **	0.105 (0.021) **	0.106 (0.015) **
Construction Year 2001-2010	0.048 (0.028)	0.042 (0.029)	0.030 (0.034)	0.058 (0.031)
Sale and Lease Back	-0.015 (0.093)	-0.013 (0.093)	-0.015 (0.090)	-0.019 (0.086)
Rent All Inclusive	0.070 (0.014) **	0.070 (0.014) **	0.069 (0.014) **	0.061 (0.013) **
Turn Key	0.164 (0.023) **	0.159 (0.024) **	0.174 (0.026) **	0.178 (0.025) **
Number of Listed Structures <150m	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Highway <150m	0.016 (0.013)	0.020 (0.013)	0.008 (0.016)	0.024 (0.012)
Railway <150m	0.034 (0.011) **	0.045 (0.011) **	0.026 (0.014)	0.034 (0.011) **
Open Space <150m	-0.016 (0.008) *	-0.023 (0.008) **	-0.010 (0.010)	-0.018 (0.008) *
Water <150m	0.006 (0.012)	0.012 (0.012)	-0.002 (0.015)	0.008 (0.011)
Station <250m	0.008 (0.013)	0.000 (0.013)	-0.011 (0.026)	-0.012 (0.014)
Building Volume <250m *(log)*	0.010 (0.010)	0.016 (0.010)	-0.006 (0.022)	-0.006 (0.010)
Mean Construction Year <250m (4)	Yes	Yes	Yes	Yes
Real Estate Agents (10)	Yes	Yes	Yes	Yes
Year Dummies (20)	Yes	Yes	Yes	Yes
Postcode Fixed Effects (145)	Yes	Yes	Yes	Yes
Number of Observations	4,792	4,792	4,792	4,792
R^2	0.702	0.700		
F-test for Weak Instruments			18.032	
Test for Exogeneity (Critical Value)			0.708 (3.841)	

Notes: Instruments in Specifications (3) and (4) are the presence of pre-war buildings and their mean height. The test for exogeneity is the robust χ^2-score. Robust standard errors are between parentheses. For Specification (4), standard errors are bootstrapped (500 replications) and the mean effect of building height is presented.

** Significant at the 1 percent level

* Significant at the 5 percent level

In Specification (3) we use instrumental variables to account for unobserved factors that may be correlated with building height. In Appendix A, Table A2, we present the first-stage results. The instruments are strong (the *F*-test is 18) and have the expected effects: the presence of pre-war buildings in the neighbourhood reduces current building height by about 11 meters (which is almost one-third of the mean) and the height of these pre-war buildings has a positive effect on building height: a 10 meters increase in the average height of pre-war buildings in the neighbourhood leads to an increase in building height of 7 meters. The effect of building height is now somewhat larger than for the OLS specification (4.2 rather than 3.0 percent).[22] We do not find evidence that building height is endogenous. The value of a Hausman exogeneity test is 0.708, much less than the 5 percent critical value of 3.841. This suggests that unobserved locational or building endowments are not, or are at least not strongly, correlated with building height.[23]

In Specification (4) we employ a control function approach to estimate the nonlinear impact of building height (see Section 3A). Table 2 highlights that the *average* impact is very similar to the effect found in Specification (3). Figure 5 presents the marginal willingness to pay for an additional 10 meters for Specifications (3) and (4). In Specification (3), we assume that the effect is constant. In line with assumptions by HS, Specification (4) indicates that the marginal effect is positive and non-monotonic. According to (4), the WTP is slightly diminishing or constant for buildings shorter than 25 meters (about 60 percent of the observations) and diminishes for buildings up to 90 meters. The latter is in line with the idea that the marginal effect of agglomeration economies is positive but diminishing in taller buildings. For buildings taller than 90 meters, the marginal WTP is increasing.

[22] Our finding that the IV effect is somewhat stronger than the OLS effect suggests that firms cluster at locations that are unattractive for unobserved reasons (e.g. due to zoning).

[23] Although we have two instruments, one cannot use an overidentification test here, as the mean height of pre-war buildings is difficult to interpret if one does not control for the presence of pre-war buildings in the neighbourhood. Overidentification tests are more relevant when the instruments are really different (Combes et al., 2011). In the next subsection we will show that our results are robust when we choose another set of instruments, and we use an overidentification test given this set of instruments.

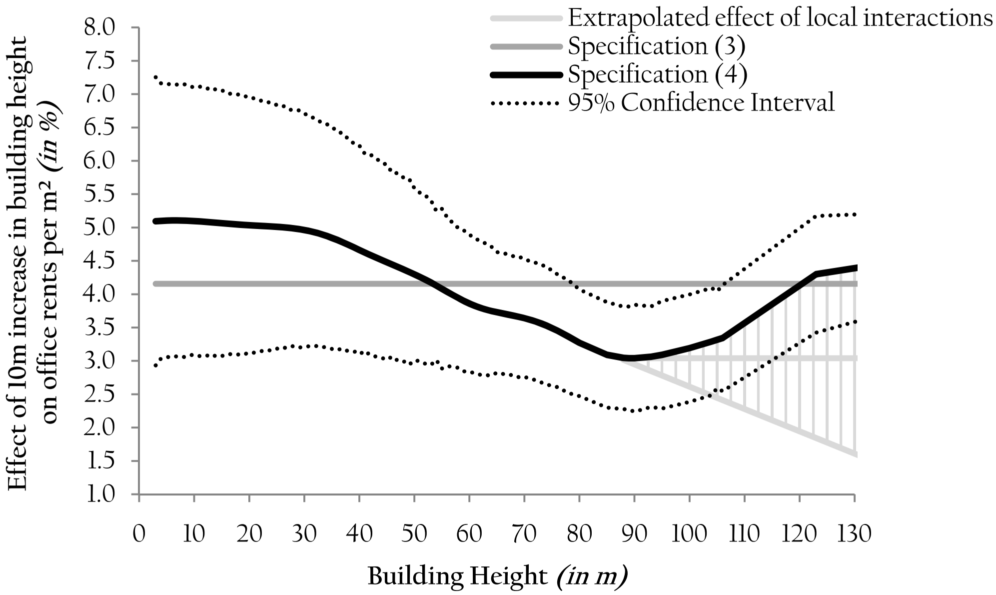

FIGURE 5 — THE EFFECT OF BUILDING HEIGHT ON COMMERCIAL RENTS

According to HS, the raison d'être of tall buildings are the sum of interactions between workers and a reputation effect. Our results support this idea and seem to suggest that within-building agglomeration economies are important. Given the assumption that the benefits of agglomeration diminish with building height, it is striking that for buildings taller than 90 meters, the WTP for buildings suddenly increases, strongly suggesting that there is a reputation effect. As there are only 20 office buildings in the Netherlands that are taller than 100 meters, these buildings seem to offer additional amenities to tenants. We indicate the magnitude of the reputation effect by the shaded area in Figure 5, given the assumption that (1) the marginal effect of agglomeration economies is constant after 80 meters or (2) given that the assumption that the effect is diminishing linearly. These two assumptions provide us with a lower and upper bound of the reputation effect. Assuming that there is no reputation effect for buildings lower than 90 meters, we establish that the reputation effect for a building of 100 meters is between 1.5 and 5.8 percent, while for a building of 130 meters (about 6 times the average height), it is between 17.5 and 36.2 percent.

Our empirical results show that nearby building volume does *not* impact land rents, so the presence of between-building agglomeration effects are not confirmed. This finding is even more extreme than the finding that the benefits of more near neighbours decay very rapidly after 250 meters (Arzaghi and Henderson, 2008).

We have to reflect on other reasons that may explain the sudden increase in the WTP for building height after 90 meters. For example, one may argue that taller buildings are *always* of higher quality, so that the instruments also capture quality effects. We think this is not a problem, because there is sufficient anecdotal evidence that not all tall buildings offer exceptional quality.[24] It is also important to note that we condition on the construction year and dummies indicating whether a building is new or renovated (which should pick up most of the effects related to quality) and use instrumental variables that take into account correlation with unobserved building endowments. Moreover, the reputation effect seems to be too large to be explained by quality differences only. It is also unlikely that the effect of the increased willingness to pay is explained by the views that employees like to have.[25] When we measure the effect of a view, we have a measurement-in-variable error problem, as we do not use (or have) information about the height of the floor that a tenant occupies, but only use building height (that is on average twice the height of the floor of the tenant, so there is a large measurement error). This creates a strong bias towards zero of the view effect (of about 50 percent if height is uncorrelated to other regressors). So, it is likely that only a small portion of the effect of building height is attributable to better views and certainly does not explain the sudden increase in rents after 90 meters.[26]

Control variables have in general plausible signs. For example, newly constructed rental properties are 5 percent more expensive. When the office is rented all inclusive, the rents are about 7 percent higher. Turnkey offices have rents that are 17 percent higher.[27] Buildings that are constructed more recently are generally more expensive, but this effect is relatively weak (which makes sense; one expects a stronger effect of building age on properties' sales prices, which captures future rent revenues, rather than on current rents). Buildings constructed between 1991

[24] For example, the building in which the authors work is tall, but of relatively low quality. Another example is that speculative developers that aim to construct the tallest building (to capture reputation effects) may construct such a building with a tight budget, implying low quality (see Willis, 1995).
[25] Real estate agents indicate that for a building of 10 floors (about 40 meters), the maximum price difference between the lowest and highest floor due to better views is only 5 percent.
[26] In subsection 4C we will pay more attention to this issue.
[27] A turnkey office is rented in a ready-to-use condition, including carpets, office furniture, etc.

and 2000 are about 12 percent more expensive than those constructed just after the war. Buildings constructed between 2001 and 2010 seem, somewhat surprisingly, less expensive than buildings that are constructed in previous decade.[28]

B. *Identification revisited*

A major concern of our identification strategy is that current unobserved characteristics of buildings and locations are correlated with the unobserved characteristics of pre-war buildings, which invalidates our IV-strategy. We therefore discuss some potential issues with respect to the identification strategy and validity of the instruments in more detail. Results are presented in Table 3.

In Specification (5), we estimate the same model, but exclude all locational attributes (such as distance to railways, building volume, etc.). When building height is simply a proxy for unobserved locational and building quality, or when the instruments are correlated with current unobserved factors, the coefficient should drastically change. However, the effect is very similar to that in Specification (3).

TABLE 3 — HEDONIC ANALYSIS OF RENTS, IDENTIFICATION ISSUES
(dependent variable: logarithm of rent per square meter)

	(5) – IV	(6) – OLS	(7) – IV	(8) – IV
Building Height *(in 10m)*	0.049 (0.008) **	0.029 (0.002) **	0.049 (0.014) **	0.044 (0.010) **
Buildings Before 1940		0.006 (0.019)		
Mean Height Buildings Before 1940		0.003 (0.001) *		
Rental Property Characteristics (23)	Yes	Yes	Yes	Yes
Neighbourhood Characteristics (11)	No	Yes	Yes	Yes
Year Dummies (20)	Yes	Yes	Yes	Yes
Postcode Fixed Effects (145)	Yes	Yes	Yes	Yes
Number of Observations	4,792	4,792	4,792	4,792
R^2		0.703		
F-test for Weak Instruments	57.994		46.741	47.206
Test for Exogeneity (Critical Value)	4.743 (3.840)		2.067 (3.840)	2.185 (3.840)
Overidentification Test (Critical Value			0.699 (3.840)	

Notes: Instruments in Specifications (5) are Buildings Before 1940 and Mean Height Buildings Before 1940. In Specification (7) we include Distance to Station 1870 and Population Density 1830. Specification (8) includes all instruments. The overidentification test is the χ^2-score. See also Table 2.

[28] The reason may be that between 1995 and 2000 there was a substantial shortage in the office market (Steinmaier, 2011). A relatively quick response to this shortage may have resulted in the construction of low quality office buildings that were completed after 2000. Another reason may be that after 2000 there was substantial excess supply of office space, which will have had a dampening effect on office rents, especially for newly constructed office buildings that have to attract new renters.

For the results presented in Table 2, we use the presence of pre-war buildings and their height as instruments for building height. Similar to Au and Henderson (2006) and Arzaghi and Henderson (2008), as a second informal test for validity, we include the instruments directly in the ordinary least squares regression of rent. When building height is correlated with unobserved endowments, the instruments will absorb some of the bias of the current building height effect. If the instruments are invalid, the coefficient of building height should decline. In Specification (6), however, we find an identical coefficient for building height compared to Specification (1), suggesting that our instruments are valid (or that building height is not endogenous). It also appears that our instruments have a very small direct impact on the current office rents.

As a third test, we use two alternative instruments (see Table A2). As a first alternative instrument we employ municipal population density in 1830 (municipalities at that time were much smaller: we have 41 of those municipalities in our three city sample). The instrument's validity rests on the assumption that population density in 1830 is unrelated to current locational endowments, but has a causal effect on the current building height (see, similarly, Ciccone and Hall, 1996; Combes et al., 2008). Concentrations of people in 1830 imply a current building stock that contains more historic structures, leading to lower building heights because of conservation policies. However, unobserved endowments of 1830 are likely unrelated to current unobserved endowments of office buildings that mainly contain business services. We also include an instrument that captures the distance to the nearest station in 1870 (while still controlling for the current distance to the nearest station). Railway stations were then an important factor enforcing agglomeration of firms and therefore taller buildings (Ciccone and Hall, 1996). Specification (7) highlights that the choice of instruments hardly influences our results: the effect of a 10 meter increase in building height leads to a slightly higher increase in rents of 4.9 percent. So, if anything, our estimates in Table 2 are conservative. The alternative instruments estimates also imply that the effect of building height is exogenous (as the value of the exogeneity test (2.067) is much less than its critical value). Because the alternative instruments have a very different nature, it is informative to apply an overidentification test. This test does not indicate that these alternative instruments are invalid.[29] In Specification (8) we include all four instruments and find, as expected, that the estimate is in between the estimated effects of building height of Specifications (3) and (7). Although the standard error of building height is now much smaller, so the power of the exogeneity test is increased, still we do not reject the exogeneity assumption.

C. *Other specifications*

In this subsection, we test some other specifications. Results are presented in Table 4. Previous studies often use density variables as a proxy for agglomeration economies (see e.g. Ciccone and Hall, 1996; Arzaghi and Henderson, 2008). In Specification (9) we exclude building height from the analysis to test whether building volume within a range of 250 meters picks up the positive effect of building height. Indeed, in (9) there is a statistically significant and (rather strong) positive effect of nearby building volume, whereas in Specifications (1)-(4), we did not find any effect of building volume within 250 meters. This suggests that excluding building height overestimates the magnitude of between-building agglomeration economies.

TABLE 4 — REGRESSION RESULTS, COMMERCIAL OFFICE RENTS AND BUILDING HEIGHT
(dependent variable: logarithm of commercial office rent in Euros per square meter)

	(9) – OLS	(10) – OLS	(11) – OLS	(12) – OLS
Building Height *(in 10m)*		0.037 (0.003) **	0.031 (0.002) **	
Building Height×Amsterdam *(in 10m)*				0.038 (0.002) **
Building Height×Rotterdam *(in 10m)*				0.017 (0.003) **
Building Height×Utrecht *(in 10m)*				0.025 (0.004) **
Building Volume <250m *(log)*	0.054 (0.009) **	0.003 (0.010)	0.013 (0.010)	0.008 (0.010)
Building Height÷Mean Building Height <250m *(log)*		-0.036 (0.011) **		
Building Surface Area *(log)*			-0.009 (0.003) **	
Rental Property Characteristics (23)	Yes	Yes	Yes	Yes
Neighbourhood Characteristics (10)	Yes	Yes	Yes	Yes
Year Dummies (20)	Yes	Yes	Yes	Yes
Postcode Areas (145)	Yes	Yes	Yes	Yes
Number of Observations	4,792	4,792	4,792	4,792
R^2	0.683	0.700	0.702	0.702

Notes: See Table 2

[29] We also test whether inclusion of the alternative instruments directly in an OLS-specification influences the results. Again, the coefficient of building height hardly changes compared to Specification (1) and the instruments do not have a statistically significant direct impact on rents. For first-stage results, see Table A2, Appendix A.

We have excluded area fixed effects to test robustness. It appears that the effect of building height is very similar and 3.1 percent. However, the effect of nearby building volume now is negative and statistically significant, suggesting that *conditional on building height* there are agglomeration *dis*economies.

We investigate whether the *relative building height* (the height relative to mean height of buildings in the neighbourhood) has an effect on office rents, in order to attempt to disentangle the effect of a view and within-building agglomeration. In Specification (10) we show that the relative building height does not alter the overall building height effect and, surprisingly, the relative building height effect is negative.[30] This suggests that high-rise districts contribute to positive reputation effects, whereas having a view is not considered as important. When we include the building height relative to the height of the tallest building within 250 meters, the effect is negative again, but not statistically significant.[31]

We also have re-estimated the model including building's own surface area (see Specification (11)). It is emphasised that the latter is measured with error (as the data on surface area of buildings is not always precise). The results are remarkably robust, as the effect of building height is now 3.1 percent. Surface area has a slight negative effect. This confirms the assumption that in our theoretical setting, building height is a proxy of within-building agglomeration economies rather than surface area.[32]

Specification (12) investigates whether the preference for building height varies between the three cities. Amsterdam has the highest effect, which is not too surprising, as Amsterdam hosts a large number of (multinational) firms that have a demand for tall buildings, whereas the number of high-rise buildings is limited. Especially for multinational firms, within-building

[30] The overall effect of the hedonic price function with respect to building height is then: $\partial \log p_i / \partial h_i = \alpha + \mu / \bar{h}_i$, where μ is coefficient of relative building height and $\bar{h}_i$ denotes the average building height within 250 meters of building i. With an average building height of 21 meters, the effect of a 10 meters increase in building height is 2 percent for Specifications (10).
[31] Recall that we do not know the floor level. Another way to figure out the impact of a view on rents is then to include building fixed effects and examine the effect of address numbers, as higher numbers generally indicate a higher floor. So, we construct an index which equals one when the observed rental property has the highest address number in a building in our dataset, equals two when the number is the second highest, etc. However, we did not find any positive and statistically significant effect of this index. Results are available upon request.
[32] We note that the correlation between building volume and height is 0.35. So, taller buildings tend to be larger buildings.

agglomeration effects as well as reputation-effects are likely to be more important (Smith and Coull, 1991; Barr, 2010b). In 'skyscraper city' Rotterdam, the effect is about half the effect of Amsterdam, which is consistent with the idea that a reputation effect is a relative effect that only applies to the tallest buildings, but also may represent the effect of an abundant supply of taller buildings.

D. The regulatory tax and height restrictions

Until now, we ignored the fact that maximum building height restrictions are the norm in many countries, including the Netherlands. In principle, mild restrictions can be justified as HS argue that few tall buildings are too high. However, this argument does not apply to lower buildings. So, we will focus on the effect of maximum height restrictions that apply to buildings for which the reputation effect is small or absent (so below 90 meters). In the literature, it is common to interpret the difference between the marginal construction costs of floor space and the marginal price of floor space as the regulatory tax. The regulatory tax is an aggregate measure of the gross costs of planning constraints, such as height restrictions (Cheshire and Hilber, 2008). Previous studies that employ this measure are assuming that the marginal price does not depend on building height. This may lead to an underestimate of the regulatory tax measure for tall buildings, as we have seen that the marginal price is increasing in building height.

We estimate the regulatory tax, using information from NVM-Strabo on *sales* transactions (instead of rent transactions used in the preceding analysis, which are difficult to compare to construction costs). So, we use the average sales price per square meter for office space in 2009 (436 observations) and then estimate the price increase due to building height using the estimates of Specification (4).[33] The marginal construction costs (MCC) are obtained from NEN, an institute which provides norms for construction costs of buildings (in particular, see NEN 2631 §3.2).[34] De Jong (2007) provides a model to calculate the costs for high-rise buildings in the

[33] So, we assume that the effect of building heights on rents also apply to sales prices. Focusing on buildings that are lower than 90 meters is useful as we then exclude the reputation effect (which is an externality) in the calculation of the regulatory tax.

[34] We verify this cost information using data provided by Bak (2009) and *http://www.constructiekosten.nl*. One may argue that we exclude costs related to parking that may be higher for high-rise buildings. Van Ommeren and Wentink (2011) estimate that for offices the average costs for parking are about 8 percent of

Netherlands. The increasing costs of elevators, site costs, construction costs, installations and foundations are taken into account. We distinguish between a lower and upper bound estimate of the MCC. In Figure 7, we present the marginal construction costs and the price up to 90 meters (by multiplying the building height with the corresponding coefficient, see Figure 5).

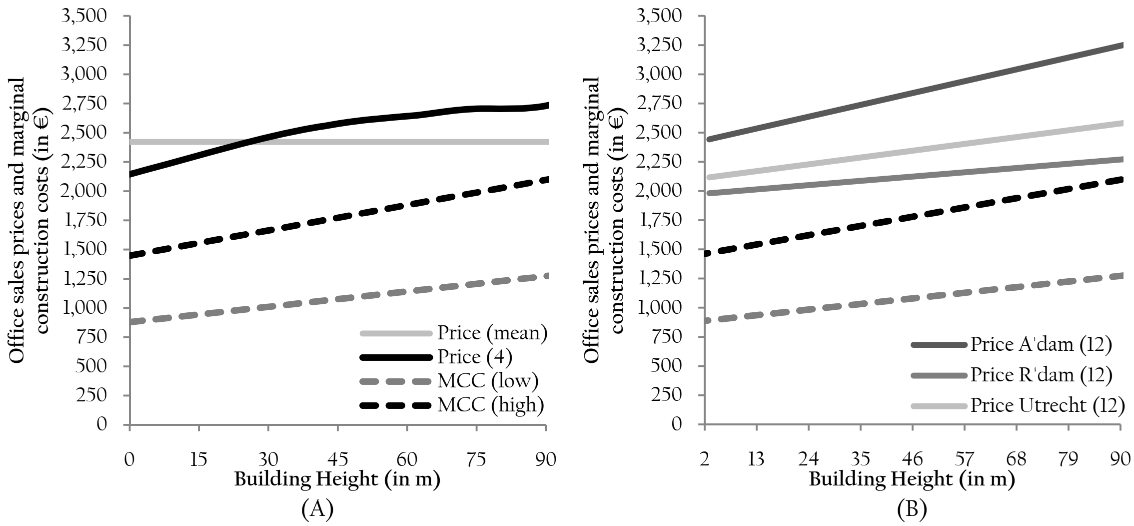

FIGURE 7 — BUILDING HEIGHT: COSTS AND BENEFITS

It is striking that the difference between the marginal construction costs and the price is about equal for different building heights (see Figure 7A). This suggests that the increase in costs of taller buildings is fully offset by higher rents, so the regulatory tax is almost independent of height in the range examined (up to 90 meters). Standard welfare economic theory implies that in order to maximise profits, building height must be such that the marginal costs of providing an additional floor is equal to the marginal willingness to pay (Glaeser et al., 2005; Cheshire and Hilber, 2008). As the price is always above the marginal costs until 90 meters (after that, reputation effects begin to play a role, which makes it difficult to derive strong conclusions), this suggests that not only tall buildings are undersupplied (at least from a developer's point of view) but also that previous estimates of the regulatory tax are underestimates for buildings taller than 25 meters. In Figure 7B we estimate the regulatory tax for Amsterdam, Rotterdam and Utrecht

the rent, which may be slightly higher for taller buildings. So, this will not change the main results presented in this subsection.

separately using the estimates of Specification (12). The regulatory tax is then the largest for Amsterdam, where sales prices (and rents) are substantially higher. This suggests that the optimal building height should be higher in Amsterdam compared to Utrecht and Rotterdam. Interestingly, in Rotterdam where building restrictions are less tight (and may be absent in certain areas), the regulatory tax is the smallest and becomes even negligible for tall buildings, given our 'high MCC' assumption.

V. Conclusions

This is the first paper that attempts to measure the economic benefits of tall buildings, beyond the reason provided by standard economic theory that tall buildings arise from economising on land rents (Mills, 1967; Lucas and Rossi-Hansberg, 2002). Helsley and Strange (2008) argue that tall buildings facilitate both internal and external returns to scale and induce reputation effects. This study demonstrates that there are substantial effects of tall buildings: firms are willing to pay about 4 percent for a 10 percent increase in building height. Given the assumption that the marginal effect of internal and external returns to scale is non-increasing, we estimate that the landmark effect is at least 17.5 percent for a building that is about 6 times the average height. Our study also shows that the regulatory tax is independent of height (up to 90 meters), suggesting that tall buildings are still undersupplied in the Netherlands. The regulatory tax is especially high for Amsterdam, but rather low for Rotterdam.

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Appendix A. Descriptives and other results

TABLE A1 — DESCRIPTIVE STATISTICS OF THE COMMERCIAL PROPERTY DATASET

	Mean	Std.Dev.	Min	Max
Rent per m² *(in €)*	143.320	51.119	50.000	450.000
Building Height *(in m)*	28.866	21.371	3.000	150.000
Building Height <20m	0.395			
Building Height 20-40m	0.431			
Building Height 40-60m	0.087			
Building Height 60-80m	0.046			
Building Height 80-100m	0.029			
Building Height >100m	0.012			
Attributes of the rental property				
Size *(in m²)*	1,131.855	1,791.571	50.000	22,000.000
New Building	0.074			
Renovated Building	0.056			
Listed Building	0.095			
Construction Year	1932.738	120.896	1200.000	2010.000
Sale and Lease Back	0.002			
Rent All Inclusive	0.025			
Turn Key	0.009			
Transaction Year	1999.540	5.536	1990.000	2010.000
Building Surface Area	2,775.554	7,384.551	19.649	66,694.650
Neighbourhood Attributes				
Number of Listed Structures <150m	11.260	30.813	0.000	224.000
Highway <150m	0.072			
Rails <150m	0.161			
Open Space <150m	0.435			
Water <150m	0.140			
Station <250m	0.070			
Building Volume <250m *(in m³)*	558,365.200	354,423.800	99,325.000	1,799,650.000
Mean Construction Year <250m	1931.123	80.100	1647.444	1999.833
Instruments				
Buildings Before 1940	0.665			
Mean Height Buildings Bef. 1940 *(in m)*	13.502	5.156	1.000	32.000
Distance to Station 1870 *(in km)*	2.586	1.633	0.049	11.077
Population Density 1830 *(per km²)*	3,416.326	5,023.820	23.102	13,707.420

NOTE: The number of observations is 4,792.

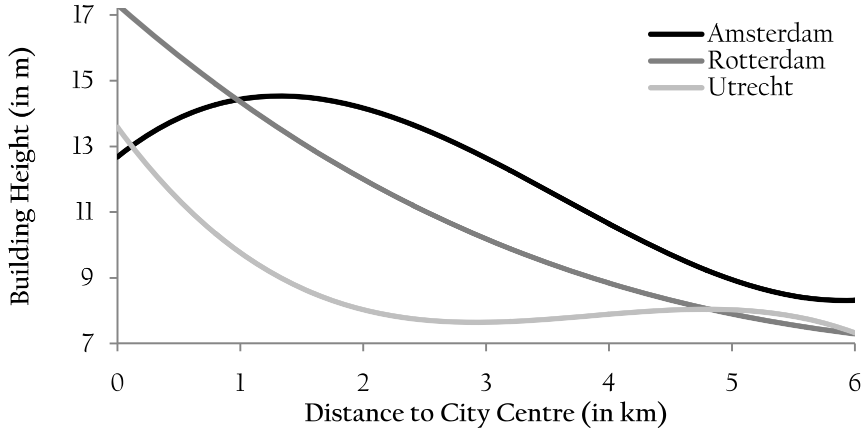

FIGURE A1 — BUILDING HEIGHT AND DISTANCE TO THE CITY CENTRE

TABLE A2 — FIRST STAGE REGRESSION RESULTS
(dependent variable: building height in 10 meters)

	(3) – IV			(5) – IV			(7) – IV			(8) – IV		
Buildings Before 1940	-1.105	(0.206)	**	-1.968	(0.189)	**				-1.404	(0.203)	**
Mean Height Bldngs. Bef. 1940 *(in m)*	0.072	(0.014)	**	0.126	(0.013)	**				0.076	(0.013)	**
Distance to Station 1870 *(in km)*							-0.728	(0.080)	**	-0.786	(0.079)	**
Population Density 1830÷1000 *(per km²)*							-0.048	(0.016)	**	-0.056	(0.015)	**
Rental Property Characteristics (23)	Yes			Yes			Yes			Yes		
Neighbourhood Characteristics (11)	Yes			No			Yes			Yes		
Year Dummies (20)	Yes			Yes			Yes			Yes		
Postcode Areas (145)	Yes			Yes			Yes			Yes		
Number of Observations	4,792			4,792			4,792			4,792		
R^2	0.545			0.460			0.551			0.559		

Notes: See Table 2.

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